Advanced Epi Tools for Gallium Nitride Light Emitting Diode Devices

Work Performed Under Agreement:

DE- EE0003331

Applied Materials, Alternative Energy Products & Advanced Technology Group

2012 DOE SSL Manufacturing Workshop

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Program Outcome/Milestones

- **Increase manufacturing throughput** by developing and assembling a multi-wafer system that can deposit high-quality GaN with a growth rate twice as fast as today's MOCVD systems

- **Decrease cycle time and improve binning yield** by demonstrating a multi-chamber MOCVD and HVPE/MOCVD system and a manufacturing process that can produce LEDs with **high internal quantum efficiency** and **minimal PL uniformity variation** within each wafer and wafer-to-wafer.

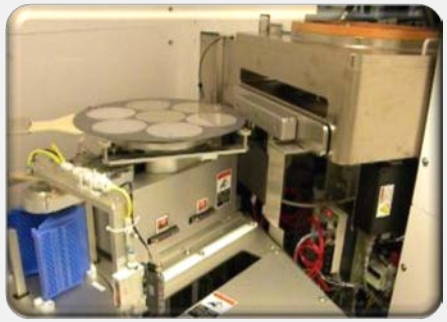
- Assure the industrial relevance of the multi-chamber MOCVD / HVPE system by developing processes that **allow it to deposit high-quality LED structures** on the most promising candidate substrate materials

- Increase throughput by developing a **novel automated *in-situ* cleaning** process

- **Design, build, assemble, and test a full-scale epitaxial growth system** for LED manufacturing in a multi-chamber configuration (MOCVD and MOCVD/HVPE chambers) with *in situ* cleaning capability.

Applied Centura NLighten MOCVD System

Multiple MOCVD Chambers



Full Automation Wafer & Carrier Handling

Vacuum Robot Mainframe Chamber

Full Computer Control

Applied NLighten MOCVD System:
Superior Device Performance, Yield and Production Cost

Integrated LED Structure Approach:

Progressive Processing

- ✓ Dedicated reactor processing enables world class run-to-run repeatability with no opening chamber, no recipe changes, no manual intervention at all

Integrated LED structure

- ✓ MQW: Sharp interface, rapid temperature ramping
- ✓ pGaN: Sharp Mg turn-on profile

Multi-chamber cluster tool

- ✓ Scalable 4-chamber modular design
- ✓ 2”, 4”, 6” and 8” wafer processing (12” extendibility)

CoO benefit

- ✓ Reduced chemical consumption vs. competitors
- ✓ Smaller footprint vs. competitor
- ✓ Less PM frequency vs. competitors

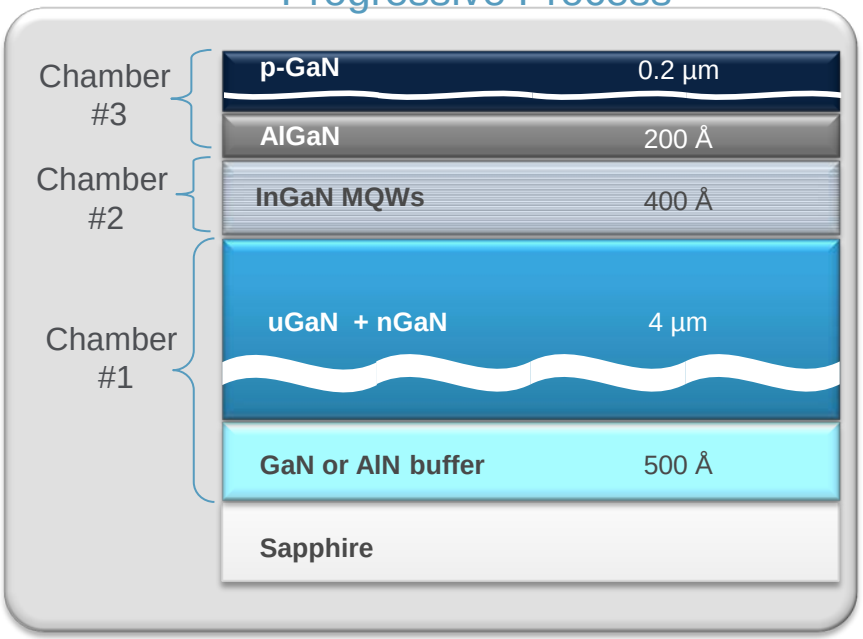
Small footprint

- ✓ High wafer out per square foot

Production worthiness with fully automated system

- ✓ In-situ chamber cleaning
- ✓ World first full automated operation and wafer handling

Progressive Process™

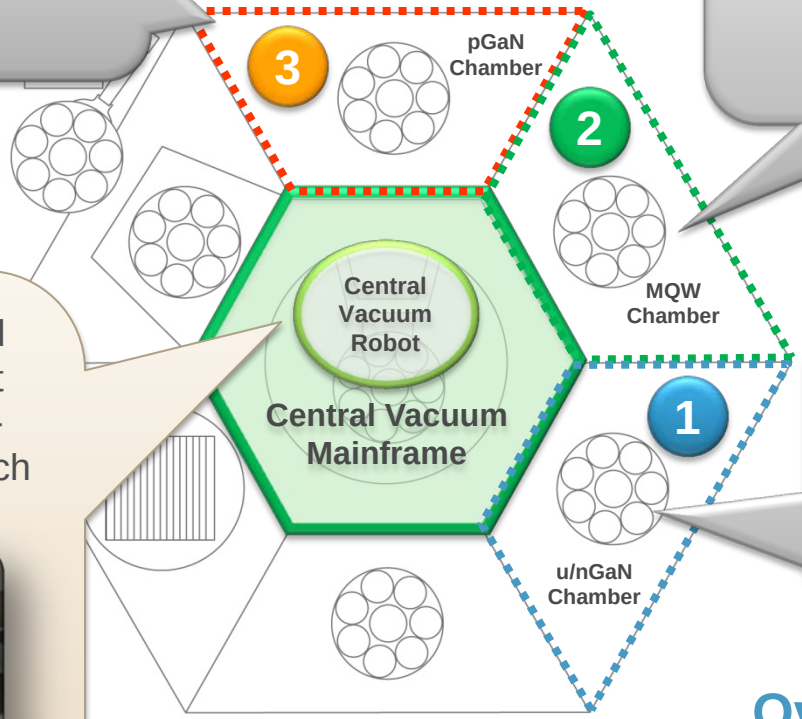


APPLIED MATERIALS®

System Configuration

Better run-to-run reproducibility by creating sharp Mg turn-on and profile

Eliminates excessive Ga (post uGaN) that depletes Indium to create more uniform and repeatable MQW pairs



Production proven Applied Centura® mainframe robot transfers wafer carriers in-vacuum to and between each chambers

Buffer growth and u/nGaN template growth HVPE

Maximize productivity with optional 4th chamber

Over 18,000 Applied Cluster Tools Installed Worldwide

APPLIED MATERIALS®

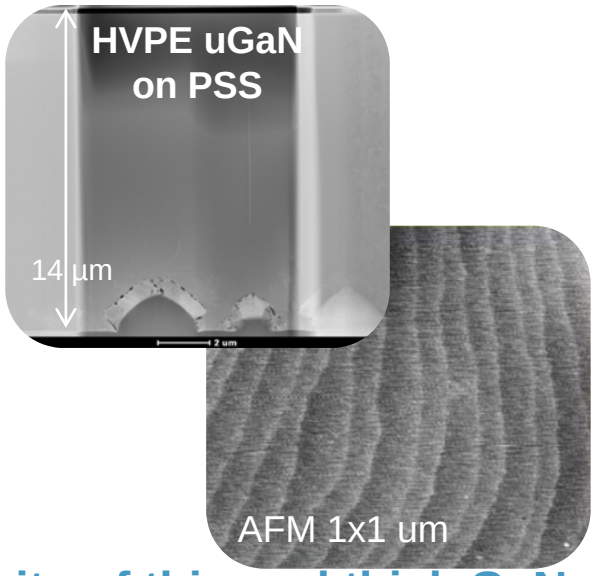
Applied HVPE Chamber

- Compact vertical chamber design
  - Cluster integration with MOCVD chambers
  - Minimal footprint
- Highest productivity and low operating cost
  - High GaN growth rate
  - In-situ cleaning enabled
- Scalability to large size substrates
  - Capable of 300mm wafer handling
- Wafer capacity per run:
  - 31 x 2”
  - 8 x 4”
  - 4 x 6”
  - 1 x 8”

Benefits of Applied HVPE Process for u/n-GaN

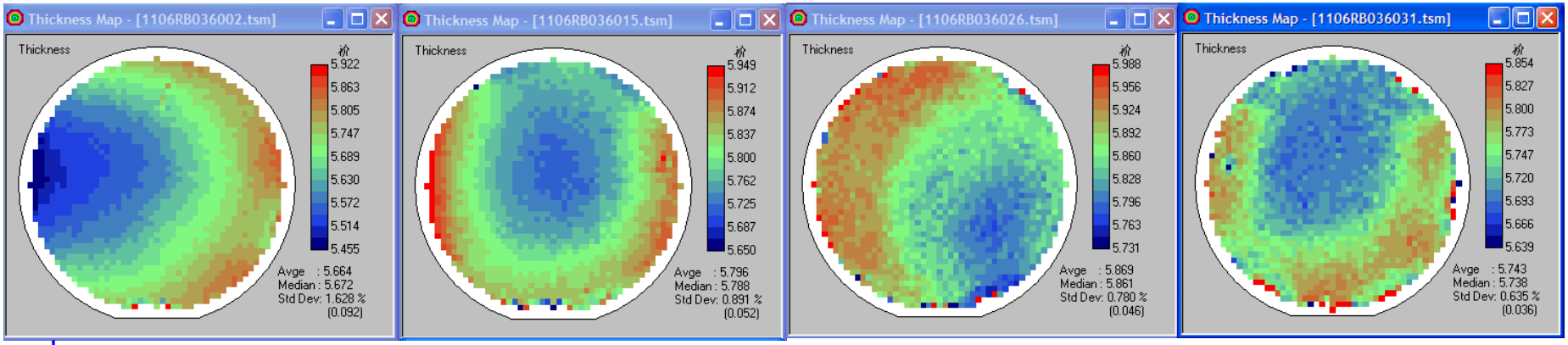
- Fast GaN deposition rates for high throughput and productivity
- Unique in-situ HVPE buffer techniques for planar sapphire and PSS
- Excellent crystalline quality GaN [XRD FWHM: (002) 90-130” ; (102) 200-250”] to enable:
  - Improvement of light extraction
  - Lower defect densities for IQE, leakage current improvement
- Process flexibility for wide range of u- and n-GaN thicknesses, and high doping levels
- Production HVPE tool with high capacity : 31x2”, 8x4”, 4x6”, 1x8”

Feature	Typical MOCVD	Applied HVPE
Growth Rate	2-3 μm/hr	10 - 100 μm/hr
Crystal Quality (on PSS)	~ 250“ (102)	~ 150” (102)
Thickness per run	4-6 μm	4-30 μm
Precursor Cost	Trimethylgallium (TMG)	Ga, >5x less than TMG



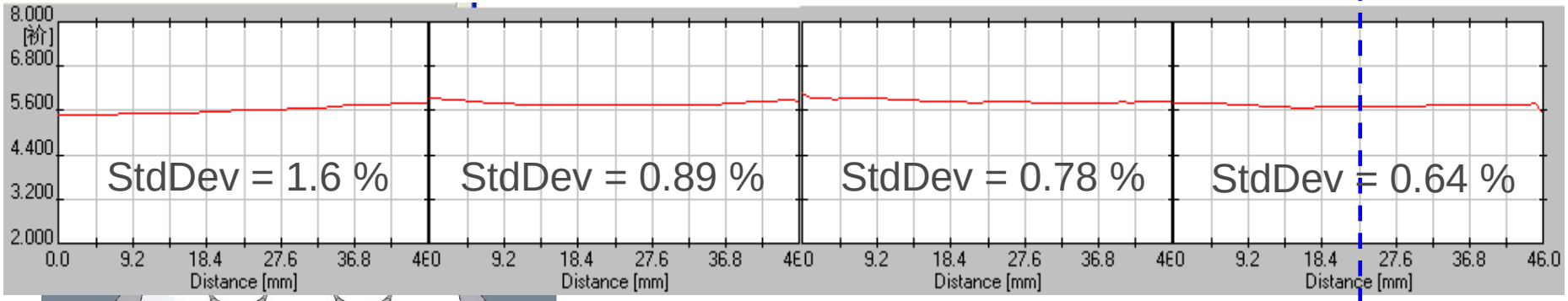
High crystalline quality & extremely low defect density of thin and thick GaN

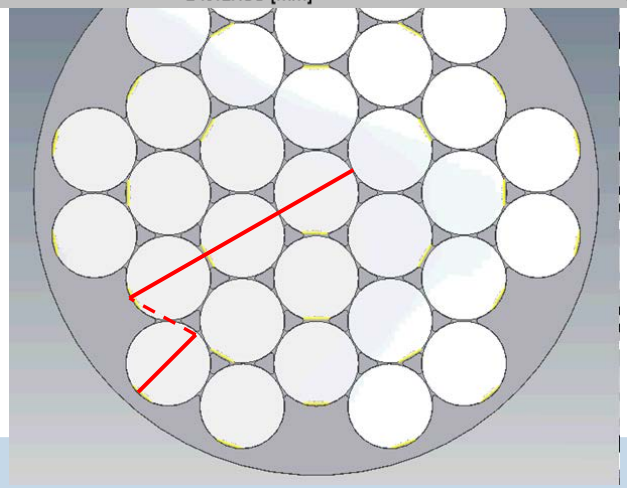
HVPE Platter Thickness Uniformity



edge

carrier center

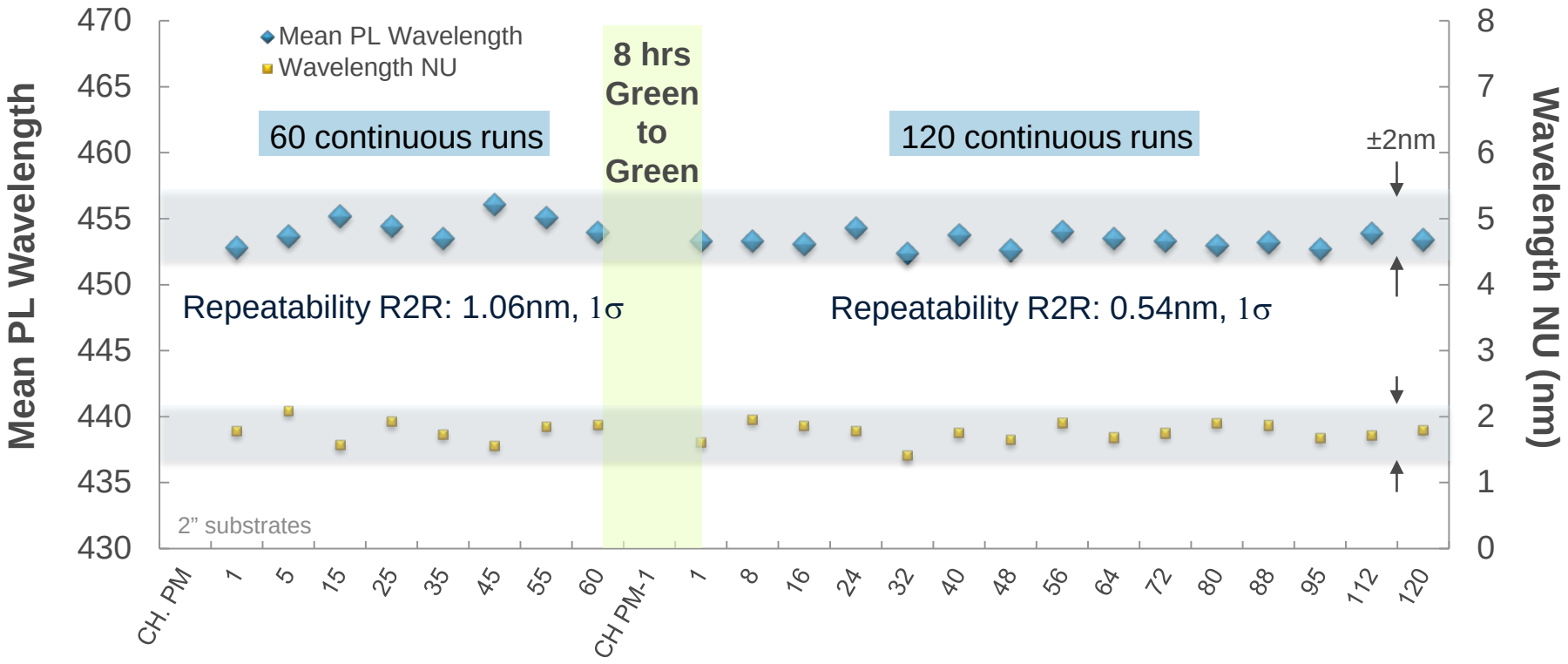




- 4 wafers on a 31×2” carrier
- Radial Uniformity
- Center wafer uniformity is excellent
- Average growth rate ~ 35 µm/hr.

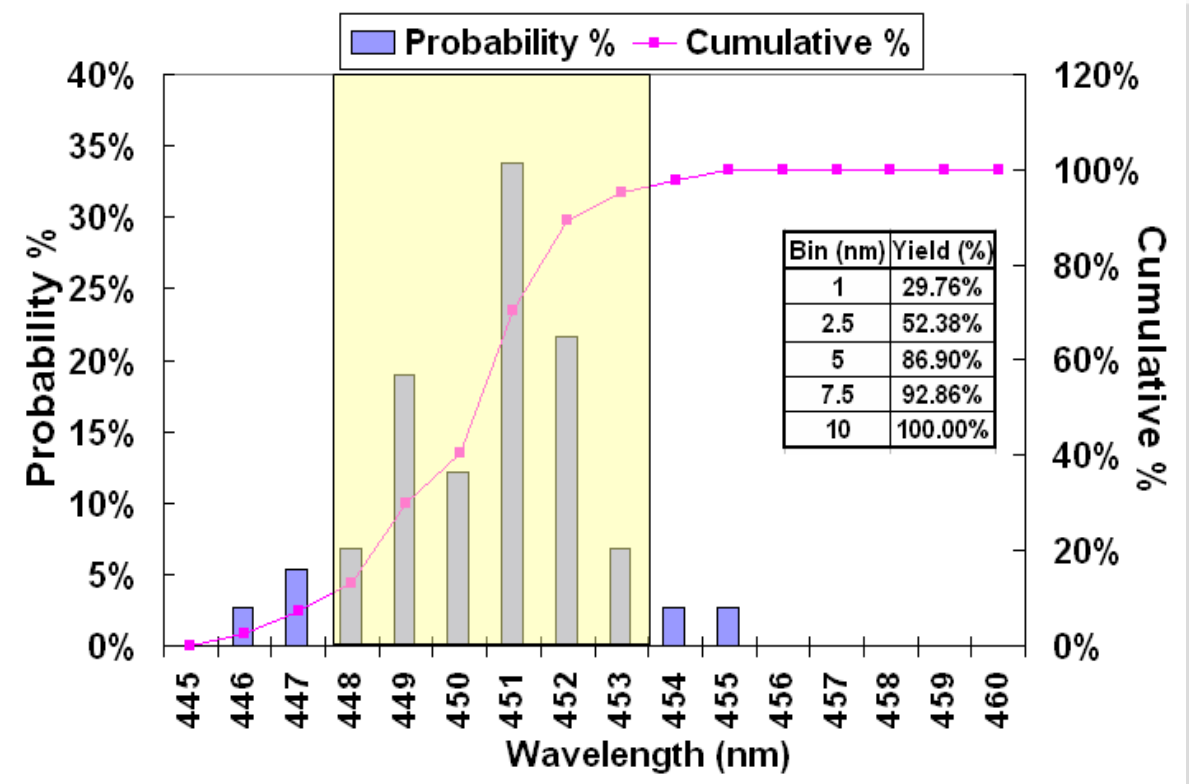
Hands-Off 120 Consecutive MQW Runs

Longest Production Cycle Before Chamber Maintenance



- 120 back-to-back runs with no manual intervention: no recipe adjustment, no chamber opening – "Hands-Off Processing"
- Rapid chamber recovery post maintenance: 8hrs green-to-green

Excellent Run-to-Run Wavelength Yield Performance



Tight wavelength distribution, matching >87% of 5nm bin to 450nm target for 5 consecutive runs

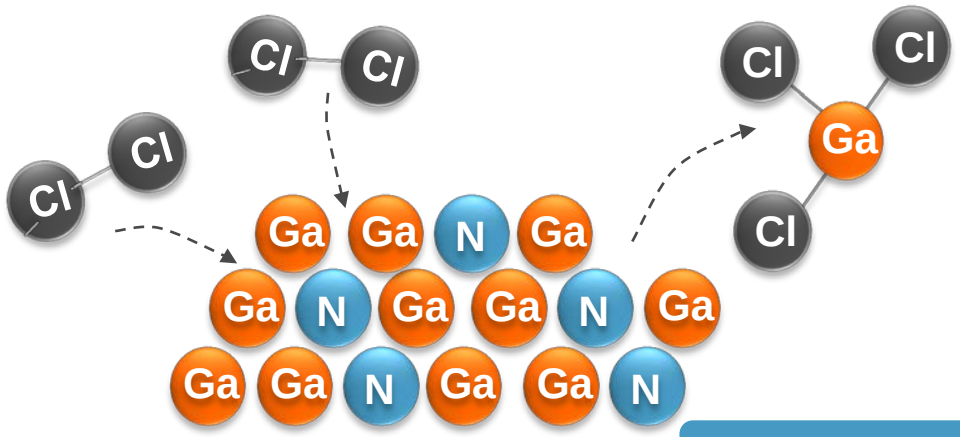
In-Situ Clean of u/n-GaN Chamber

Coated Showerhead

- MOCVD and HVPE capability
- Thermally-enhanced chlorine clean to remove Ga-rich GaN deposits on chamber surfaces
- Two simultaneous processes: chlorination of GaN; sublimation of $GaCl_x$
- Fast etch rates for high chamber productivity
  - Optimized showerhead temperature, chlorine flux, chamber pressure

Clean Showerhead Following In-Situ Process

$Ga_{>1}N_{<1} + Cl_2 \rightarrow GaCl_x + N_2$

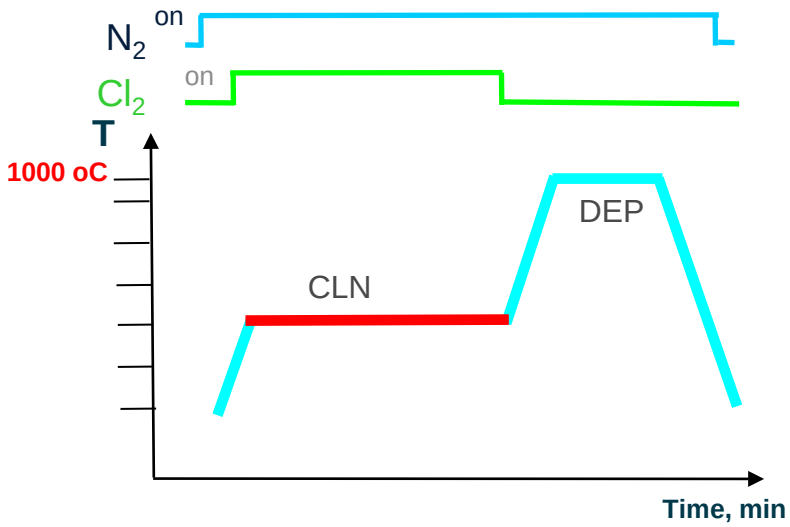


HVPE Process Established with *in-situ* Clean

- HVPE chamber allows to keep high temperature during cleaning cycle. As a result, the chlorine based cleaning is more effective in HVPE chamber than in MOCVD chamber with cold showerhead.

Cleaning and Deposition sequences for HVPE process

DEP ⇨ CLN ⇨ DEP ⇨ CLN ⇨ DEP ⇨ CLN ⇨ DEP ⇨ CLN



The duration of current HVPE process

GaN thickness	5-6 μm	10-11 μm
Process Time (Growth + Clean)	2.7 hours	2.8 hours
u/nGaN Growth Time	100 minutes	110 minutes
Clean Time	60 minutes	60 minutes

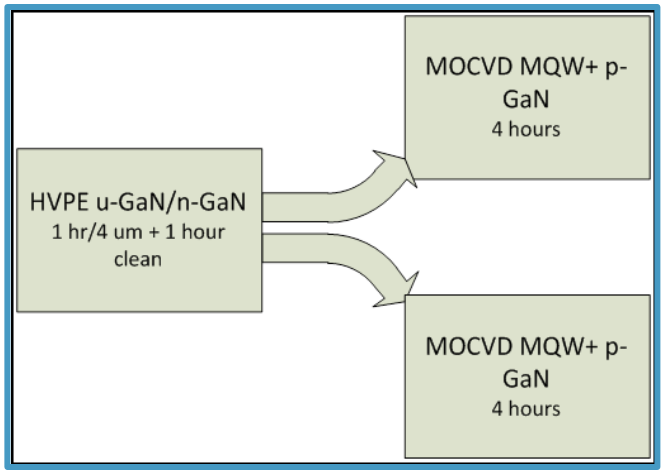
No need to open chamber after each CLN run. The chamber is ready for next DEP run.

Excellent Throughput Performance

- **Sequential 3 chamber process (“1 + 1 + 1”)**

  - The cycle time per run can be reduced to 3.3 hrs.

- **Newly developed Parallel 2 chamber process (“1 + 2”)**
  - One HVPE chamber to deposit u/n-GaN film
  - 2 MOCVD chambers to deposit MQW and p-GaN layers simultaneously as shown
  - A cycle time of 2.3 hrs. can be achieved, far exceeding the program goal of 3.5 hours by 35%.



Summary

- Introduced world-class cluster MOCVD system and processes for LED volume production
- Demonstrated production worthy HVPE chamber and processes
- Developed the world's first HVPE + MOCVD integrated system and processes
  - Highest throughput, lowest operating cost and most compact design
- Developed processes that ensures high repeatability, high yield and world-class LED performance
- ***Department of Energy funding was essential to enable these critical R&D efforts***

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